830

COMPUTERS IN AGRICULTURE 1994

Proceedings of the
5th International Conference

Edited by
Dennis G. Watson
Fedro S. Zazueta
Tony V. Harrison

6-9 February 1994
Orlando, Florida

Published by
American Society of Agricultural Engineers
2950 Niles Rd., St. Joseph, Michigan 49085-9659 USA

Library of Congress Card Number 93-74815
International Standard Book Number 0-929355-46-6
ASAE Publication 03-94

AUTOMATED IMHOFF CONE CALIBRATION AND SOIL LOSS/INFILTRATION ANALYSIS FOR FURROW IRRIGATION STUDIES

R.D. Lentz and R.E. Sojka[1]

ABSTRACT

Furrow-irrigation-induced soil erosion is a serious threat to sustainable agriculture globally. The significance of this threat has been fully appreciated only recently, resulting in increased interest in irrigation-erosion studies. Analysis of infiltration and runoff data from furrow-irrigation research is cumbersome and time consuming because calibration functions relating sediment settling-volumes in Imhoff cones to sediment concentration must be obtained for each treatment. Moreover, the manipulation of water and constituent runoff data for plotting and treatment comparison is awkward and tedious. The Pascal program described in this paper (FUROFIGR) reads experimental data from a text file and derives, displays, and statistically compares Imhoff calibration functions for any user-defined furrow group. It employs the computed or a user-supplied calibration function to calculate infiltration, runoff, and sediment loss for each furrow. Additional software (SEDTIME, PLOTSED) computes and plots group-averaged values for cumulative sediment loss and outflow sediment concentration as a function of irrigation duration. This software represents a significant advance over existing manual calculation techniques or previously reported software.

KEYWORDS. Furrows, Irrigation, Soil Erosion, Sediment discharge, Estimation methods, Furrow Infiltration.

INTRODUCTION

The extent of soil losses from irrigated fields has recently been recognized (Carter, 1990; Hajek et al., 1990). Furrow irrigation produces significant erosion on surface irrigated lands of Idaho and the Pacific Northwest. Soil losses range from 5 to 50 t ha^{-1} yr^{-1} (Berg and Carter, 1980) in South-Central Idaho, representing 1 to 25 times the soil loss tolerance (t) values for these soils. Highly erodible soils are surface irrigated on 1.5 million ha in the Pacific Northwest.

Expanding research efforts are examining problems and solutions of irrigation-induced erosion, increasing the need for quick and reliable techniques to determine soil loss in irrigation outflows. One technique employs Imhoff cones to measure sediment in runoff samples. A calibration function correlates the sediment volume settled after 30 min with sample sediment concentration (weight per unit volume runoff). Details of this method were reported by Sojka et al. (1992). Soil loss and infiltration resulting from furrow irrigation can be derived if furrow inflow and outflow rates over inclusive intervals are measured.

Furrow erosion studies generate large data sets; their analysis requires numerous repetitive calculations. Furthermore, data interpretation is incomplete if the dynamic character of irrigation parameters is not visualized. The manipulation, analysis, and display of such data is most easily accomplished using specially designed computer software. Software currently available for use in treatment comparison studies either do not have the capability to compute Imhoff cone calibration functions or lack more sophisticated facilities for treatment or

[1] R. D. Lentz, Research Associate, Dept. of Agric. Eng., University of Idaho, 3793 N 3600 E., Kimberly, ID 83341; R. E. Sojka, Soil Scientist, USDA-ARS, Kimberly, ID 83341.

experimental factor comparisons (Sojka et al., 1993). Our objective was to develop a comprehensive Pascal program (FUROFIGR) with file debugging aids and advanced data grouping capabilities. It computes individual or piecewise calibration curves and statistically compares resulting functions (e.g. among treatments). Net infiltration is calculated, and calibration functions are employed to estimate runoff sediment and net soil loss for each furrow. Two other programs (SEDTIME, PLOTSED) compute and plot group-averaged values of cumulative sediment loss, outflow sediment concentration, and flow rate as a function of irrigation duration.

IRRIGATION MONITORING REQUIREMENTS

Field measurements are made on each experimental furrow of interest. These include irrigation inflow, outflow, and settled sediment volumes from 1-L runoff samples collected in Imhoff cones. Measurements are made at specific intervals throughout the irrigation. Identifying codes, furrow spacing and length are noted for each furrow. Time and inflow rate are recorded whenever furrow inflow is adjusted. Time, outflow rate, and sediment volume are recorded at each sampling interval. Outflow rate and sediment volume are typically measured at 5 and 15 min after furrow advance, then every 30 min during the next 3 h. From then on, measurements are made hourly, with a final measurement made just prior to inflow shut off. In addition, four to ten runoff samples representing the sampling range are collected from Imhoff cones for each treatment. These are filtered in the laboratory and sediment mass is used to compute calibration functions (see following section). Details on furrow monitoring and filtering techniques were reported elsewhere (Lentz et al., 1992; Sojka et al., 1992).

HARDWARE REQUIREMENTS AND DATA INPUT

The programs require an IBM compatible PC with 640k ram memory, and DOS 2.0 or higher operating system. Drivers for several output devices are included, both Epson 86e (9 pin) and HP Laserjet IIIsi (PCL and postscript modes) have tested well. FUROFIGR reads the raw data from an ascii (text) file. An example input file, with accompanying definitions is presented in Table 1. Information for each furrow is entered as a block, beginning after the initial data file title record. Computer data entry is simplified if measurements are recorded on a well organized field data sheet (e.g. see Sojka et al., 1994).

IMHOFF CONE CALIBRATION FUNCTIONS

The program computes Imhoff cone calibration functions for up to 11 different groups defined by one or more of the furrow identifiers (see Table 1). The ability to declare group types permits one to determine those treatments or factors that require unique calibration functions. Sediment mass of collected calibration samples are regressed on the corresponding Imhoff settled-sediment volumes using the least squares method. Sediment concentration (SCONC_i), in g L^{-1} for each irrigation interval (i), is estimated from the calibration equation:

$$\mathrm{SCONC}_i = \mathrm{B} \bullet \mathrm{SVOL}_i + \mathrm{C} \qquad (1)$$

where **B** is the slope, **C** is the Y-intercept, and SVOL_i is the Imhoff cone settling volume (mL). Optionally, the user may request a piecewise linear regression, entering the sediment volume value at which slope transition occurs.

The program then tests for similarity among calibration functions using an ANOVA F test (Neter et al., 1983, p. 342). Up to four of any of the groups can be tested at one time. After defining groups to be employed in the analysis, the program asks for the number and identification of groups to analyze. Regression functions for each group are computed and both lines and data points are displayed (Fig. 1), permitting a rapid graphic assessment of regression fit. Next, a statistical comparison between the groups' calibrations is completed; and the functions are displayed on screen, along with F-test statistics (Fig. 2). This information determines whether unique calibrations are required for each group.

Table 1. Input File Format For **FUROFIGR** With Sample Data.

Actual File	Definitions
Test data (Cntrl.dat)	Title
06/19/91	Irrigation Date
1 0 170	FURROW IDENTIFIERS: Irrig. #, Irrig. Type, Day of Year
6 1 0 0	FURROW IDENTIFIERS: Furrow #, Rep., Trtmt., Furrow Type (optional)
1.12 171.8	Furrow Spacing (m), Furrow Length (m)
3	# of Inflow Records ($\geq$3, Including 1st & last)
10 01 0	Hr and Min 1st rate began, Inflow rate (gpm)
10 01 6	Hr and Min 2nd rate began, Inflow rate (gpm)
18 01 0	Hr and Min 3rd rate began, Inflow rate (gpm)
10 33 0 0 -1	Time flow reaches flume (Flow & Sediment = 0)
10 38 4.3 9.0 15.5 -1	Hr, Min, Outflow (cm & L min^{-1}), Imhoff sediment Vol., Wt. (mL & g L^{-1})
11 03 4.4 10.0 -1* -1	*If no sediment vol. is available, enter -1; however the initial sample
11 33 4.5 12.0 17.5 14.8	record must include a sediment volume value
12 03 4.6 12.0 19.5 16.5	
12 33 4.6 11.0 15.5 -1*	*If No Filtered Sediment wt. for Calibration, Enter -1 in Last Column
13 03 4.6 12.0 13.0 11.0	
13 33 4.6 12.0 11.5 9.7	
14 03 4.6 11.0 9.5 -1	
14 33 4.6 11.0 11.0 -1	
15 03 4.8 13.0 11.0 -1	
15 33 4.8 13.0 11.3 9.5	
16 03 4.6 12.0 12.5 10.5	
16 33 4.6 12.0 13.0 11.0	
17 03 4.4 10. 10.2 -1	
17 33 4.5 11.0 8.0 -1	
18 03 4.4 10.0 8.0 -1	
18 10 0 0 0 -1	Time Flow Ends at Flume (Flow & Sediment = 0)
-99	Code to Mark end of Data for Current Furrow

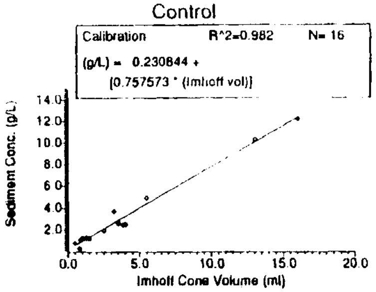

Fig. 1. Calibration function and incorporated data points. Up to four displayed or printed per page

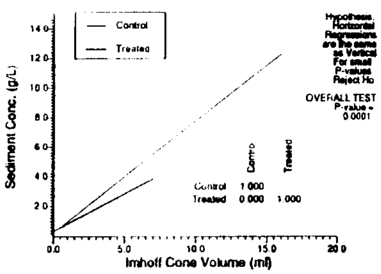

Fig. 2. Display of compared calibration functions and F-test statistics.

INFILTRATION AND SEDIMENT LOSS CALCULATIONS

Program Sequence

When calibration function analysis is complete, the program requests the user to specify which calibration function to apply to each of the previously selected furrow groups. Output values are then calculated for all furrows in each group. At this point a program prompt permits the user to request a data display for individual furrows (Fig. 3). The display includes graphs of outflow rate, accumulated sediment loss, and outflow sediment concentration, plotted as a function of irrigation duration. The graphs are accompanied by a numerical summary of the furrow output.

The software outputs computed values to a text, or ASCII file, which is readily imported into statistical or graphics software. Furrow identifiers are included to aid in sorting data. Each data column in the output file is labeled. Calculated outputs include mean outflow in L min^{-1}, total sediment loss in kg/ha, total inflow in mm, total outflow in mm, total infiltration in mm, mean sediment concentration in g/L, depth of soil loss in mm, infiltration in inches, and furrow advance time in minutes (time required for the water to traverse the dry furrow).

The program also outputs a second file, which contains irrigation duration data utilized by two other programs, **SEDTIME** and **PLOTSED**. These software permit tabulation of furrow data based on group or furrow identifier. Compiled irrigation parameter values, cumulative soil loss, runoff sediment concentration, and outflow rate are averaged within the defined groups and plotted as functions of irrigation duration (Fig. 4).

Computations

Each irrigation is divided into $n+1$ periods of duration ($\mathbf{P}_i$) min, where n is the number of samples taken during the irrigation. Each ith period ends at t_i min, where $\mathbf{t}_i$ are sampling times. The first period starts when inflow begins (t_0), and ends when water first exits the furrow (t_1). Inflow rate (QIN_i) and runoff rate (QOUT_i), given in L min^{-1}, and Imhoff cone settling volume (SVOL_i), recorded as mL sediment per 1-L outfall sample, are measured at the end of each period. The one exception is the 2nd period. In this period, more representative values are obtained when measurements are taken 5-10 mins after runoff begins. The final period should begin near the time that inflow is stopped. A runoff measurement is made at the beginning of this last period and the time runoff ceases is noted. The program assumes constant runoff sediment-loads during the 2nd and last periods. Additional program inputs include an estimate of soil surface bulk density (**BD**) in Mg m^{-3}, in the furrow.

Outflow for each period ($\mathbf{OUTP}_i$) in L is computed from:

$$\mathrm{OUTP}_i = \int_i^{i+1} \left(\mathrm{Mt} + (\mathrm{QOUT}_i - \mathrm{Mt}_i)\right) dt = 0.5 \bullet \mathrm{P}_i \bullet (\mathrm{QOUT}_i + \mathrm{QOUT}_{i+1}) \qquad (2)$$

where

$$\mathrm{M} = (\mathrm{QOUT}_{i+1} - \mathrm{QOUT}_i) \bullet \mathrm{P}_i^{-1} \qquad (3)$$

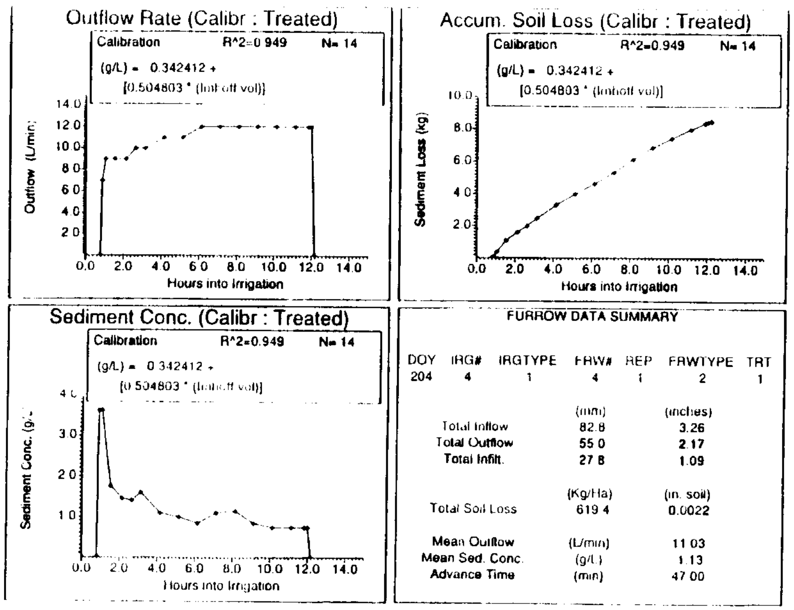

Fig. 3. Display option for individual furrow output.

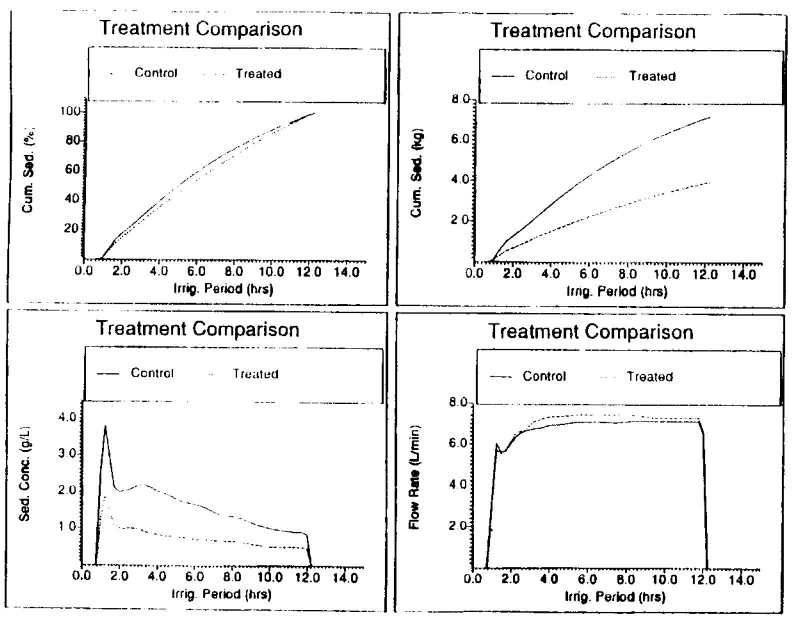

Fig. 4. Display of group-averaged irrigation parameter values plotted as a function of irrigation duration.

Net infiltration (**INFILT**) in L during the irrigation is computed from:

$$\mathrm{INFILT} = \sum_{i=1}^{n} (\mathrm{QIN}_i \bullet \mathrm{P}_i) - \mathrm{OUTP}_i \qquad (4)$$

Total soil loss from the furrow (**SLOSS**), in grams, is computed from Eq. [1], with

$$\mathrm{SLOSS} = \sum_{i=1}^{n} \mathrm{SCONC}_i \bullet \mathrm{QOUT}_i \bullet \mathrm{P}_i \qquad (5)$$

and converted to an area basis using

$$\mathrm{SLOSS}_A = (\mathrm{SLOSS} \bullet 10)(\mathrm{FRWLEN} \bullet \mathrm{FRWSP})^{-1} \qquad (6)$$

where **SLOSS_A** has units kg ha^{-1}, **FRWLEN** is furrow length (m), **FRWSP** is the inter furrow distance (m), and SLOSS is given in grams. Depth of total soil loss (**SLOSS_D**) in mm is calculated from:

$$\mathrm{SLOSS}_D = \mathrm{SLOSS}_A (\mathrm{K} \bullet \mathrm{BD})^{-1} \qquad (7)$$

where the conversion constant K = 10^4 kg m^3 (Mg ha mm)$^{-1}$. If inflow rate is not provided, erosion is estimated, but not infiltration.

REFERENCES

1. Berg, R. D., and D. L. Carter. 1980. Furrow erosion and sediment losses on irrigated cropland. J. Soil Water Conserv. 35:267-270.

2. Carter, D. L. 1990. Soil Erosion on Irrigated Lands. In: B. A. Stewart and D. R. Nielsen (eds.) Irrigation of Agricultural Crops. Agronomy Monograph no. 30. pages 1143-1171. ASA-CSSA-SSSA, Madison, WI.

3. Hajek, B. F., D. L. Karlen, B. Lowery, J. F. Power, T. E. Schumacher, E. L. Skidmore, and R. E. Sojka. 1990. Erosion and soil properties. In: Larson, W. E., G. R. Foster, and R. R. Allmaras (eds.) Proceedings of Soil Erosion and Productivity Workshop. U. of Minn. St. Paul. 13-15 March, 1989. Bloomington, MN. pages 23-39.

4. Lentz, R. D., I. Shainberg, R. E. Sojka, and D. L. Carter. 1992. Preventing irrigation furrow erosion with small applications of polymers. Soil Sci. Soc. Am. J. 56:1926-1932.

5. Neter, J., W. Wasserman, and M. H. Kutner. 1983. Applied Linear Regression Models. Richard D. Irwin, Inc., Homewood, Illinois. 547p.

6. Sojka, R. E., D. L. Carter, and M. J. Brown. 1992. Imhoff cone determination of sediment in irrigation runoff. Soil Sci. Soc. Am. J. 56:884-890.

7. Sojka, R. E., R. D. Lentz, and J. A. Foerster. 1994. Software utilizing Imhoff cone data to estimate furrow-irrigation erosion. J. Soil Water Cons. (In Press).